TECRA: C2 Application of Adaptive Automation Theory

Ewart J. de Visser[1,2], Melanie LeGoullon[1], Don Horvath[1], Gershon Weltman[1], Amos Freedy[1], Paula Durlach[3], and Raja Parasuraman[2]

[1]Perceptronics Solutions, Inc.
1001 19th St. N Suite 1500
Arlington, VA 22209
910-200-8596
edevisser@percsolutions.com

[2]George Mason University
4400 University Drive MSN 3F5
Fairfax, VA 22030
910-200-8596
edevisse@gmu.edu

[3]U.S. Army Research Institute
12350 Research Parkway
Orlando, Fl, 32826
407-384-3983
paula.durlach@us.army.mil

Abstract—This paper describes the design and initial positive evaluation of a prototype adaptive automation system to create an enhanced command and control (C2) infrastructure for more effective operation of unmanned vehicles.[1,2] Our main project objective is to apply recent advances in cognitive engineering and display automation to create Technology for Enhanced Command and Control of Small Robotic Assets (TECRA). The initial goal is an enhanced C2 system for small unmanned aircraft vehicles (SUAVs). Our approach is to use adaptive display technology to improve shared situation awareness between the SUAV Commander and the SUAV Operator, to provide new channels of Commander-Operator communication, and to reduce Commander workload.

At the core of our approach is a tri-modal *adaptive interface display* which involves adaptive information presentation in order to balance workload and to promote effective human-system performance. This novel design came about as a direct result of field observations during a full-scale military exercise and a cognitive task analysis (CTA) based on these observations. Using the CTA, we designed the basic Commander's adaptive interface format and automated triggering methods. A priori GOMS analysis predicted a 50% decrease in time on task, based on a subset of representative tasks. Data collection to date supports these predictions. Furthermore, feedback from subject matter experts and comparisons between user performance on TECRA versus an existing SUAV platform suggests that TECRA is easier to use, quicker to learn, and provides more capabilities to the user than current systems.

These results demonstrate how the TECRA application – driven by a cognitive analysis of the Commander's task, by a mission model of the anticipated Commander's needs, and by mission templates and real-time robotic data – has been able to validate theories of human-automation interaction in real-world domains such as unmanned aviation and military command and control.

TABLE OF CONTENTS

1. INTRODUCTION

Military forces of the future will use mixed manned and unmanned forces for a broad variety of functions: reconnaissance and surveillance, logistics and support, communications, forward-deployed offensive operations, and as tactical decoys to conceal maneuvers by manned assets. Mandates to reduce manning in the military have led to initiatives to assign multiple heterogeneous unmanned vehicles to a small number of human team members. The goal of such robot-human teams is to extend manned and unmanned capabilities and act as "force multipliers", as in the US Army Future Combat System [1,2,3]. Robot-human teams introduce a new and unique aspect to the planning, coordination and evaluation of unit performance.

Among the most successful fielded unmanned systems are the Small Robotic Assets (SRAs), both Small Unmanned Air Vehicles (SUAVs) and Small Unmanned Ground Vehicles (SUGVs). Recent successes in Iraq have provided an indication of their potential for revolutionizing the way U.S. troops conduct operations. SUAV scout planes and sensor systems have made it easier to spot insurgents and roadside bombs, thus saving lives.

As a result, the U.S. Army is committing increased resources to developing enhanced surveillance, communications and weapons for SUAVs. Off-the-shelf SUAVs such as the fixed wing Raven are currently deployed in sizable numbers. By March 2006, for example, the Raven had been deployed on more than 15,000 sorties or deployments totaling 18,673 flight hours. With regard to new platform technology, Army spokesman LTC John Kelleher has said, "We are going to compare what is out there – the commercial, off-the-shelf, fixed wing assets, such as Raven – with the ducted-fan technology that the Army is developing, and we will make a decision on which way we are going to go."

There are many essential human factors that need to be

[1] 978-1-4244-3888-4/10/$25.00 ©2010 IEEE
[2] IEEEAC paper#1264, Version 1, Updated 2009:11:01

Report Documentation Page

Form Approved
OMB No. 0704-0188

1. REPORT DATE **MAR 2010**	2. REPORT TYPE	3. DATES COVERED **00-00-2010 to 00-00-2010**

4. TITLE AND SUBTITLE **TECRA: C2 Application of Adaptive Automation Theory**	5a. CONTRACT NUMBER
	5b. GRANT NUMBER
	5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)	5d. PROJECT NUMBER
	5e. TASK NUMBER
	5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **Perceptronics Solutions, Inc,1001 19th St. N Suite 1500,Arlington,VA,22209**	8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)	10. SPONSOR/MONITOR’S ACRONYM(S)
	11. SPONSOR/MONITOR’S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT

Approved for public release; distribution unlimited

13. SUPPLEMENTARY NOTES

2010 IEEE Aerospace Conference, 6-13 March, Big Sky, MT.

14. ABSTRACT

This paper describes the design and initial positive evaluation of a prototype adaptive automation system to create an enhanced command and control (C2) infrastructure for more effective operation of unmanned vehicles.1,2 Our main project objective is to apply recent advances in cognitive engineering and display automation to create Technology for Enhanced Command and Control of Small Robotic Assets (TECRA). The initial goal is an enhanced C2 system for small unmanned aircraft vehicles (SUAVs). Our approach is to use adaptive display technology to improve shared situation awareness between the SUAV Commander and the SUAV Operator, to provide new channels of Commander-Operator communication, and to reduce Commander workload. At the core of our approach is a tri-modal adaptive interface display which involves adaptive information presentation in order to balance workload and to promote effective human-system performance. This novel design came about as a direct result of field observations during a full-scale military exercise and a cognitive task analysis (CTA) based on these observations. Using the CTA, we designed the basic Commander?s adaptive interface format and automated triggering methods. A priori GOMS analysis predicted a 50% decrease in time on task, based on a subset of representative tasks. Data collection to date supports these predictions. Furthermore, feedback from subject matter experts and comparisons between user performance on TECRA versus an existing SUAV platform suggests that TECRA is easier to use, quicker to learn, and provides more capabilities to the user than current systems. These results demonstrate how the TECRA application ? driven by a cognitive analysis of the Commander?s task, by a mission model of the anticipated Commander?s needs, and by mission templates and real-time robotic data ? has been able to validate theories of human-automation interaction in real-world domains such as unmanned aviation and military command and control.

15. SUBJECT TERMS

<table>
<tr><td colspan="3">16. SECURITY CLASSIFICATION OF:</td><td rowspan="2">17. LIMITATION OF ABSTRACT
Same as Report (SAR)</td><td rowspan="2">18. NUMBER OF PAGES
12</td><td rowspan="2">19a. NAME OF RESPONSIBLE PERSON</td></tr>
<tr><td>a. REPORT
unclassified</td><td>b. ABSTRACT
unclassified</td><td>c. THIS PAGE
unclassified</td></tr>
</table>

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std Z39-18

optimized for the SUAV operators themselves, and there is much research being done to address these issues. Neumann and Durlach [4] provide a brief review of factors affecting a user's ability to teleoperate a robot or vehicle, and many other publications cover this ground also. The presently proposed paper, however, focuses on the equally important but relatively neglected problem of coordination of SUAV operator and unit commander team performance. It is important to assure that commander-operator team performance is optimized with respect to such key factors as efficient communication, teamwork, well-distributed workload and effective operation of the SUAV system in order to realize the full potential contribution of the SUAV. This is particularly true as manning considerations make it more likely that one unit commander will control a number of small robotic assets, thus further complicating the team interactions. Accordingly, there is a pressing need for analysis of and technological solutions to the problems currently preventing effective command and control of small robotic assets.

The most critical problem areas in the command and control of SUAV assets include:

(1) **Inadequate information flow from the SUAV to the small unit Commander**. The Commander has insufficient information on current and planned SUAV operations, and inadequate contextual knowledge with which to interpret and guide the progress of the overall mission.

(2) **Poor coordination between Commander and SUAV operator(s)**. There is typically little or no common view of the SUAV' activities and capabilities, a limited voice communications channel, and consequently a high frequency of miscommunication regarding the long term and immediate mission objectives and tasks.

(3) **Limited commander training in terminology and technical details of the vehicle operation**. This lack of knowledge exacerbates communication problem and contributes to system ineffectiveness and/or failure.

(4) **Inadequate systematic methods for training and feedback**. This includes no standard after action review (AAR) methodology for commander-operator coordination, no standardized team performance measures and no evaluation metrics to inform systematic training.

This paper describes the design and initial investigation of a prototype command and control system aimed at creating an enhanced C2 infrastructure that allows more effective operation of unmanned vehicles. To demonstrate and test this prototype, we decided to use small unmanned aircraft vehicles (SUAV) as our initial target platform because of their immediate importance to current military operations, and because analysis has shown that the current absence of an adequate command infrastructure is a key detriment to their fully effective utilization. In addition, we selected the Raven SUAV as our specific use case and evaluation testbed.

We describe the Raven SUAV platform, followed by a detailed description of our design and prototype system. We follow this with a summary of the interviews that we conducted with subject matter experts (SME) who reviewed our system. We conclude with a description of an experiment aimed at validating our design prototype and testing the efficacy of the interface.

2. The Raven SUAV System

The Raven is a compact, lightweight SUAV that can be prepared and hand-launched in minutes for the purpose of conducting aerial intelligence, surveillance, and reconnaissance (ISR) missions during infantry combat operations, including urban warfare operations/MOUT. The basic Raven package consists of the battery powered air vehicle (AV) and a set of video camera payloads, a ground control unit (GCU) and a remote video terminal (RVT) which is essentially a GCU without uplink capability [5,6]. Figure 1 shows the normative Raven C2 configuration for the most recent RQ- 11B+ Version. The components are as follows:

Vehicle Operation—The SUAV is normally operated by a 2-person team of Vehicle Operator (VO) and Mission Operator (MO) who are located close together. The SUAV is flown directly by the VO using the GCU, which displays the direct video view from the SUAV as well as flight information such as coordinates. Mission planning in terms of waypoints, modes, etc., as well as mission monitoring, adjustment and review is done by the MO on a dedicated PC using the specialized Talon Tool for the general FalconView map display program.

Data Transmission—Flight control data from the VO and MO stations are transmitted by radio to the SUAV. These data include the mission waypoints, mission modes, etc., as well as direct flight commands, and are stored on-board the SUAV. The SUAV re-transmits the stored mission data along with real-time updates as flight status data and also transmits real-time video information. The data transmitted from the SUAV are displayed in various formats on the GCU, the Talon Tool enabled FalconView PC and the RVT.

Command—The Commander under whom the Raven is being flown is typically located remotely from the VO/MO operating team. He monitors the mission on his RVT, which displays the real-time video signal and a superimposed set of flight status information. He may also use a PC with FalconView maps for improved situation awareness, but the

FalconView application will not include Raven real-time flight status information.

Communication—The Commander communicates with the MO and/or VO using voice over a radio net. He may communicate directly or through an intermediary, generally the fire control officer. The VO and MO normally communicate with each other directly as they are usually close enough together, but also share the radio communication net.

3. Adaptive Automation Design Methodology

Our challenge was to design an adaptive interface for commanders that facilitated information flow between the SUAV and the humans and enhanced commander-vehicle operator coordination. A further challenge was to design our new interface so that it could work together with the current Raven SUAV system. In the current Raven system, the commander primarily has a RVT that serves as the main source of visual imagery from the SUAV. The RVT display is identical to that of the VO, and consists of several flight parameters superimposed over a video scene (see Figure 2).

Our approach was to 1) enhance the current commander's display by adaptively displaying relevant information as the mission progressed, and 2) extend the current capabilities of the system by turning the display into a portal through which the commander could access advanced features and communicate intent to the Raven operators. We used our own adaptive design methodology that consisted of five steps.

Step 1: Field Observations

Extensive field observations were conducted at two locations (Ft. Benning, GA and Ft. Polk, LA) in order to understand the commanders' tasks and their information needs.

At Ft. Benning, the observations focused on Army doctrine, training, and schoolhouse knowledge of small UAVs by observing a day of training at the Small Unmanned Aircraft System (SUAS) Course. During this day, current Raven operators were being trained to become Raven instructors for their units. At Ft. Polk, we observed company commanders and their infantry units over several days of a week-long full-scale exercise intended to prepare Army units for upcoming deployments.

The observational data collected from both locations resulted in a wealth of information including 50 hours of field observations, 2 hours of audio transcriptions and over 3 hours of videotape footage from interviews with Raven operators, a copy of the current Raven manual, and classroom presentation materials from the SUAS course.

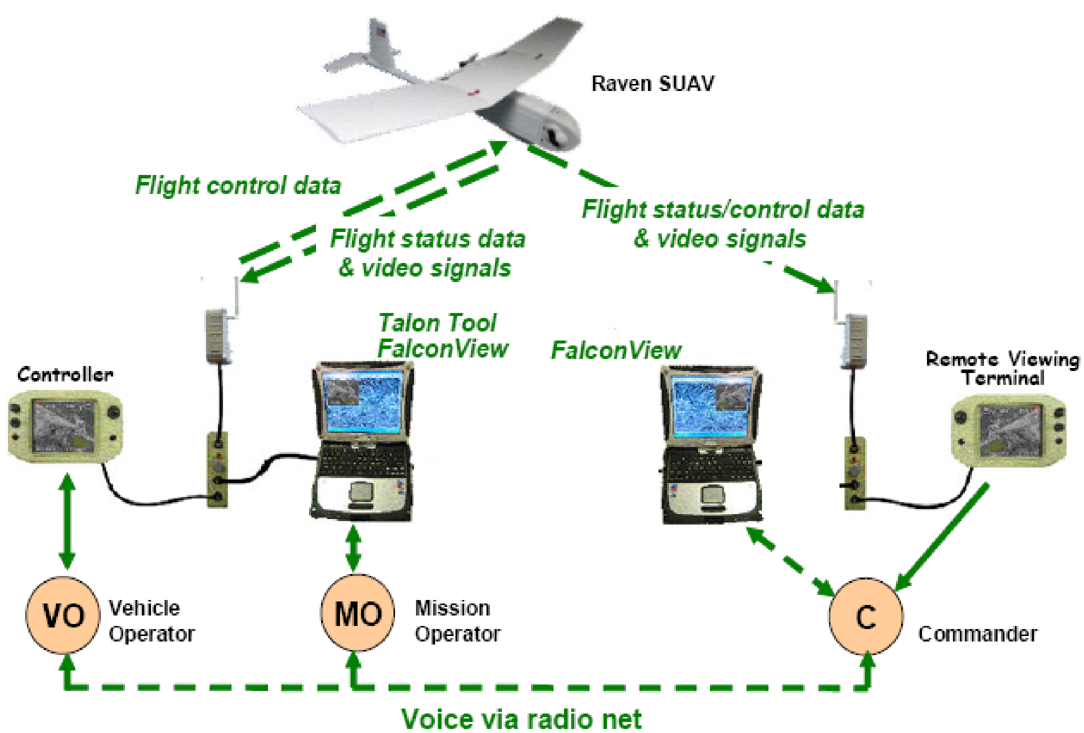


Figure 1 - Normative Raven Command and Control setup

Figure 2 - Commander's RVT display

Step 2: Cognitive Task Analysis

Using the knowledge gained from the schoolhouse doctrine and manuals, we developed a comprehensive Hierarchical Task Analysis (HTA) that highlighted the typical tasks a commander performs during a Raven mission as well as the specific information requirements associated with those tasks. This task analysis was then used to prepare probes for the field observations made during the training exercise. The results from this second trip served to inform a modified version of Klein, Calderwood, and MacGregor's [7] Critical Decision Method Cognitive Task Analysis (CTA).

The HTA and the CTA revealed an interesting pattern. The commander's tasks could be sorted into three general task categories: monitoring the current video feed, reviewing past information, and re-tasking the vehicle in-flight. We refer to these categories collectively as *mission phases*.

In addition to this emergent categorization of tasks, the CTA helped identify several bottlenecks that might plague a typical mission. The most common (and arguably the most disruptive) bottleneck was the radio communications between commander and Raven operators, as shown by the operational sequence diagram (see Figure 3). Factors contributing to this bottleneck were radio frequency congestion, intermediaries, and the absence of the message recipient.

A second bottleneck stemmed from the commander's incomplete understanding of the Raven system, which sometimes leads to additional radio communications. A final bottleneck was the slow manner in which information obtained by the Raven was distributed from the command post to the rest of the company.

Step 3: Preliminary Adaptive Interface Design: Overview

Our newly proposed design was a departure from the current system in which the commander must make do with raw flight data and spend precious time waiting for queries, re-tasking directives and responses to be relayed over the radio net to the vehicle operators. Using the bottlenecks listed above as critical areas of improvement, we identified three main system requirements to guide our design. First, the new interface **must reduce reliance on verbal radio communications**. Second, the interface must **be intuitive**.

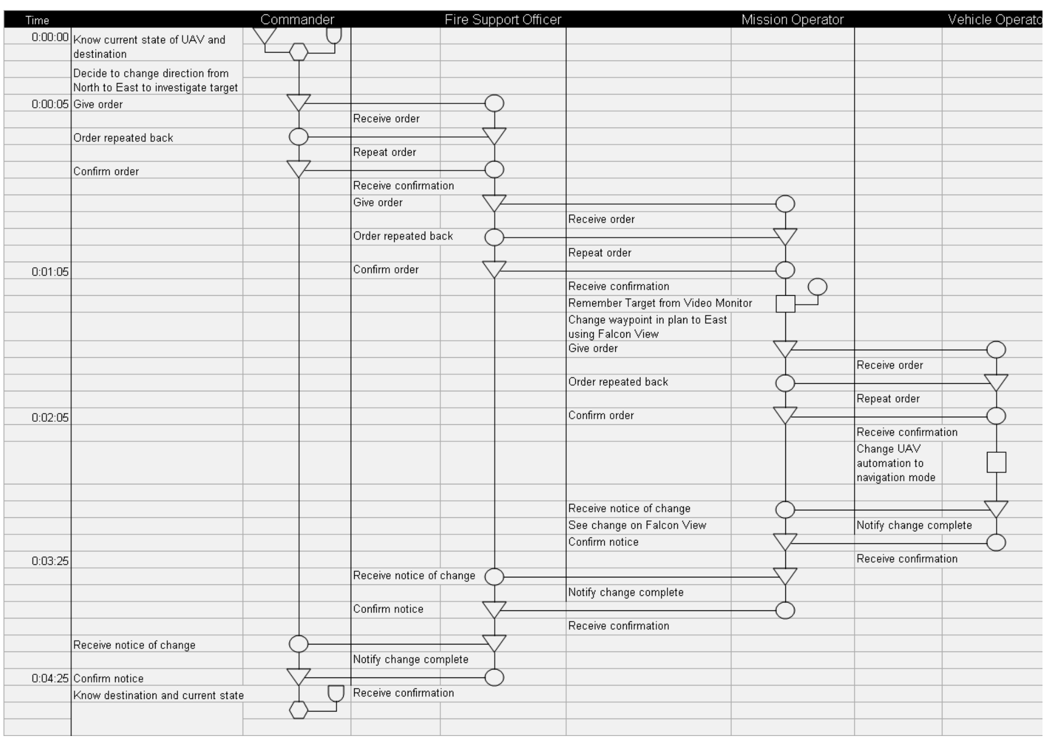


Figure 3 – Operation Sequence Diagram showing communications bottleneck for commander

And third, the interface must facilitate the **production of products for later consumption**, such as during patrols and After Action Reviews (AARs).

In short, we envisioned an interactive display that bypasses the brittle and cumbersome nature of voice radio communications by creating a data link between the interfaces of the commander and the operators.

Mission Modes

We proposed three analogous Mission Mode displays based on the three distinct mission phases identified by the CTA. These give the commander the flexibility he needs to manage the UAV asset effectively based on his information needs and time available. The modes are briefly described below and displayed in Figure 4.

Monitor Mission Mode Display—The Monitor view is the default view and will allow the commander to watch the Raven video feed in real-time. The video display is largest in the configuration to allow easy situation awareness assessment by the commander. The current location of the asset is readily available in a thumbnail map while details of what is being tracked appear in the mission analysis panel.

Review Mission Mode Display—The Review Mission view allows the commander to examine stored imagery of targets and landmarks that have been obtained by the Raven. In this mode the commander can flip through captured images, and video clips, obtain distances for roads and landmarks, read target-specific information entered by the MO, and mark up the images with several annotation tools in the Mission Analysis panel.

Change Mission Mode Display—The change mission mode allows the commander to quickly signal a course change to the Raven team when needed. The map is largest in this configuration to allow accurate flight plan review and in-flight re-tasking requests.

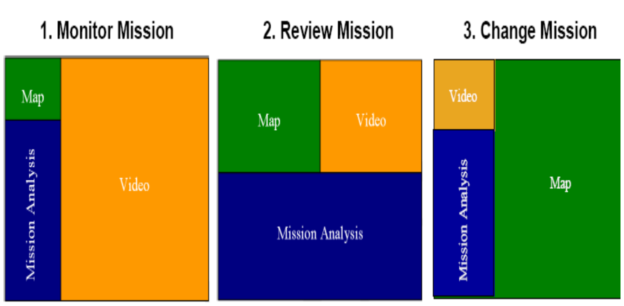


Figure 4 - The three modes: Monitor, Review, and Change Mission Mode

Step 4: Selecting Invocation Methods

The proposed interface will switch modes adaptively based on (1) mission type, (2) critical events, and (3) individual preferences of the commander. The critical question is: Which invocation points should trigger the adaptive mode selection and when should they be activated?

Our approach to this issue was to use the goals and methods from the HTA to build a GOMS model for the commander. The methods in this model describe the specific goals a commander can accomplish with the interface. The decisions represent the choices the commander has to make when accomplishing these goals. The selection rules describe which procedural IF-THEN rule the commander can follow when multiple options are available. The model provides a useful framework to support the various invocation methods.

Mission Type—Different missions require different goals to be accomplished. For instance, reconnaissance missions typically have a specific aim in mind such as "verify target X is at location Y" while surveillance involves a more general goal of observing whatever can be seen. Depending on the mission at hand, mission specific goals can be included or excluded from the model.

Critical Events—During a mission, certain events may require an interface adaptation. For example, upon spotting a suspicious car, an operator engages the *loiter* mode and the *left* camera for the Raven. Following such a sequence, the commander's display could switch to the Monitor Mode:

```
Selection Rule for Goal: MONITOR MODE

        IF Flight mode = Loiter and Camera = Left
and Monitor Mode = off,

        THEN Accomplish Goal: SWITCH TO MONITOR
MODE

        IF Flight mode = Loiter and Camera = Left
and Monitor Mode = on,

        THEN Accomplish Goal: MAINTAIN MONITOR MODE
```

Commander Preference—The system can also learn the preferences of commanders by monitoring and analyzing their goals and decisions and incorporating such information into a Bayesian network. For example, one commander may frequently take a picture of the same object of interest. The system may offer to take the picture for commanders if they have a high probability of deciding to do so.

Step 5: Implement and Validate Method of Invocation

One of the well-documented benefits of GOMS is the ability to make *a priori* predictions about performance times of expert behavior. Thus, we tested the feasibility of our design in the very early stages of development by comparing the predicted performance times of our proposed interface against the predicted performance times of the current system for three representative tasks. The results showed a 48% improvement in performance time, shaving almost 5

minutes off a nearly 10 minute series of tasks. Based on these very promising results, we could justify continued development of the new design.

4. The TECRA Prototype

The TECRA prototype was designed to create a new command and control infrastructure that will support the Commander and improve Commander-Operator team performance. Another goal was to enhance Commander-Operator coordination. Based on analyses described in the previous section, we developed an integrated Commander's display that combines video, navigational, and mission information. The TECRA system's Commander display makes use of existing, as well as new mission information data links to facilitate shared situation awareness among the Commander and the SUAV Operators throughout the mission. This section describes in detail the TECRA functionality and interface design.

TECRA-Raven Configuration

The projected new TECRA-Raven configuration is shown in Figure 5. The most important elements are described below:

Additional flight data sent to TECRA Commander interface—The flight status data can be provided to the Commander's PC via an already available connection from the RVT unit. This data incorporates mission planning and route data entered by the MO, representing almost all of the information available on the MO's PC, as well as real time SUAV data. This new information will be supplied to the Commander via the new TECRA Commander Interface.

New MO-CMDR data link will enhance communication and shared awareness—In addition, a new radio-based data link is established between the Commander's and the MO's PC, which will enable (1) direct texting between the two team members, to improve mission-related communication, and (2) transmission to the Commander's PC of MO inputs not included in the SUAV downlink signals to improve shared awareness by coordinating the two displays.

TECRA Commander's Interface

A completely new interface was designed and developed for the mission Commander (see Figure 6). This interface consists of the tri-modal adaptive component display. The three mission modes correspond to specific mission tasks that Commanders typically engage in. The specific TECRA interface components are described below:

Area Map—The area map (upper left) is synchronized with the vehicle operator's FalconView, giving a common picture of the authorized airspace, planned route, and areas of interest. Commanders can draw directly on the map for their own use, print off copies for dissemination, or send the

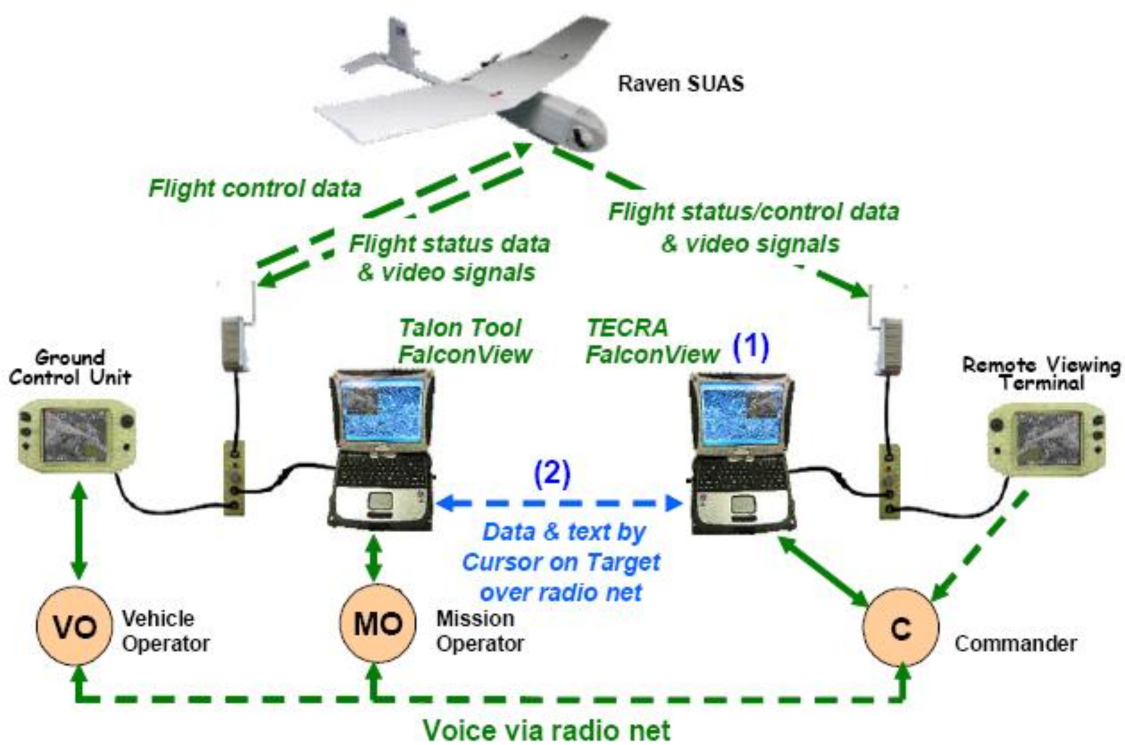


Figure 5 – Projected TECRA-Raven C2 Configuration

markup to the operators for a clear explanation of their intent. Commanders can also create suggested waypoints or routes and submit them to the vehicle operators for review.

Video Feed—The video feed (upper right) comes directly from the UAV and presents selected flight data. Commanders can freeze the frame, rewind, fast-forward, take screenshot pictures, and even record video clips, while the mission is underway. The field of view is depicted on the map, not just showing the commander "Where am I?" but also "What am I looking at?"

Mission Timeline—The mission timeline (lower left) is able to track multiple vehicles and record events such as waypoints, when photos and video clips were taken, and user-created bookmarks for later review.

Saved Media Library—The saved media library (middle left) gives easy access to screen captures and video clips, which are sorted and listed in a library of locally stored pictures and videos. Each item is tied to a geographical location which appears on the map when the image is reviewed.

Message Center—The message center (lower right) lets Commanders communicate with their operators through a built-in chat feature that enables users to send/receive queries and updates, as well as coordinates and mark-up symbols.

Toolbar—The toolbar (far right) permits editing of both maps and images, with built-in drawing tools. In addition to these tools, the Commander can also save and export new images to external applications.

5. SME Evaluation

The first step in evaluating our new TECRA interface was to have military commanders use it and evaluate its efficacy. We recruited officers at Ft. Campbell to participate in this study. Results of this study are described in this section.

Method

We had a sample size of six, including three Captains, one Lieutenant, and two enlisted service members from 1st and 3rd BCTs.

Our sessions ran about 2 hours. We began with an interview to gauge the background of the participant, and then introduced the TECRA system. Participants learned the

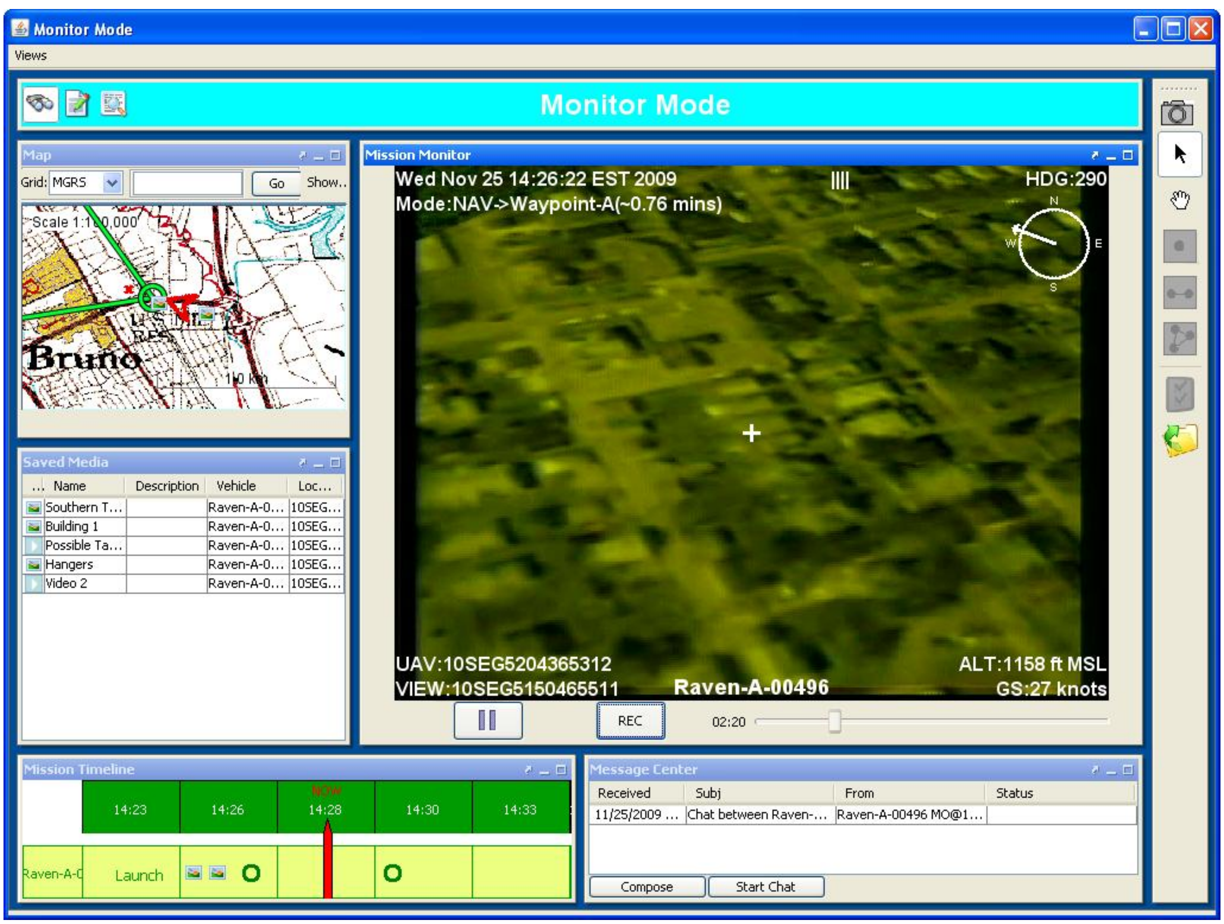


Figure 6 – TECRA Commander Interface

basics of the system via one-on-one training, and then were asked to perform the similar tasks on their own. All audio was recorded, as were keystrokes and screenshots. When time was tight, this training session was reduced to a demonstration, and feedback was elicited from the participant during the demo. Following the TECRA session, we administered another questionnaire that focused on the interface.

Results

The responses to TECRA were overwhelmingly positive. The commanders we spoke with confirmed that our system adds functionality they currently do not possess, as did the Raven operators. In addition, commanders rated the system as user-friendly and easy to learn. Some of their actual comments included:

(1) "It's a pretty simple system. I would use this."

(2) "I think this is useful in a laptop version or being able to interface on a website based thing… on a computer in a company CPU would be very useful."

(3) "Yeah, I mean it all seems pretty user friendly, especially if you sat down and played with it a few times. It's pretty quick to figure out."

(4) "I think this is a good little system."

6. EXPERIMENTAL STUDY

Our next goal was to evaluate the TECRA system more formally. In particular, we were interested in comparing the current remote viewing terminal (RVT) system to our new TECRA system and determining if we would find any performance benefits. We decided to simply compare the currently used RVT interface with the newly designed TECRA interface.

Several measures were used in this experiment to compare the two interfaces. Besides performance on tasks, we were particularly interested in two important human performance issues including maintaining or improving situation awareness and balanced mental workload. One major system design goal is to facilitate high levels of situation awareness for all team members involved. This is a major concern for UV operators, but it is also important for Commanders or other individuals consuming sensor data from the UV. By increasing the situational awareness of UV customers, the overall mission should become more efficient.

When shared situational awareness is not employed, inefficient human-robot teaming may result. Situation awareness issues such as unreliable voice communication between a commander and vehicle operator or a lack of a common view of the asset's activities between the commander and the operator may cause unnecessarily high cognitive demands, in an already highly cognitive demanding and stressful environment.

TECRA is designed to make it easy for users to find information on the screen and in particular, to help inform users where they are geographically and what they are looking at. Theoretically, this design should improve situation awareness when they are using the system. In addition, subjectively experienced workload should be reduced because the display was designed to be sparse only showing those elements that are useful to the operator, therefore hypothetically reducing the effort needed to locate critical information.

We therefore predicted that users of the TECRA software would have an easier time locating information and thus show an increase in situation awareness for the TECRA system compared to the current RVT display. We also predicted a decrease in subjectively experienced workload. In addition, we expected that users would perform better on target detection tasks compared to the RVT.

Method

Twelve students from George Mason University (4 Males and 8 Females) participated in this study and were compensated with course credit. After signing an informed consent form, the experimenter read the experimental instructions to the participant. Participants were also shown picture examples of the targets that they were instructed to identify. Participants did not receive any training on either of the two SUAV monitoring interfaces. This was done so we could examine how easy it was to learn to use either of these systems.

Target Detection Task—Participants were asked to monitor a video feed from an SUAV using the new prototype TECRA interface and the currently used RVT interface. The task was to identify target buildings. The majority of the scenery displayed on the video feed was two dimensional graphics. Targets consisted of 3-dimentional buildings, which would appear intermittently throughout each scenario. Participants were instructed to respond to each target by pressing a button and briefly describing the size and color of the building.

Situation Awareness Task—In addition to the target detection task, participants were also instructed to simultaneously answer questions sent to them via instant "chat" messages. Messages were sent once every 35 - 45 seconds. Participants were asked to respond to each message by typing and sending their answer via the chat window. Two types of questions were asked: secondary distracter questions (simple arithmetic problems); and Situation Awareness (SA) questions. The SA questions concerned the

current state of the SUAV. These questions included:

(1) What waypoint is the vehicle heading toward?

(2) What is the ground speed of the vehicle?

(3) What is the altitude of the vehicle?

(4) What direction is the vehicle traveling (cardinal direction or heading)?

These specific questions were chosen as measures of SA for two reasons: 1) each of these four characteristics (upcoming waypoint, vehicle speed, vehicle altitude, and vehicle direction) were identified as important pieces of information for the Commander, especially when making a route request, and 2) both the TECRA interface and the RVT interface display this information, therefore making it possible for the participant to answer all SA questions using either of these interfaces.

In both conditions (TECRA interface and RVT interface) all of the information needed to answer the SA questions was included on the video feed overlay. However, the two interfaces displayed and organized the information differently.

Participants completed four trials, two trials using the current RVT system and two trials using the TECRA prototype. Each trial lasted approximately 10 minutes and consisted of 12-14 targets and 8-11 situational awareness questions.

The conditions were counterbalanced to account for ordering effects. Participants also completed the NASA-TLX workload index after each trial.

Results

All data was analyzed using a 2x2 Repeated Measures ANOVA with condition Interface Type (RVT, TECRA) and Scenario (1,2). Results described include data for target detection accuracy and reaction time, situation awareness and subjective workload.

Target Detection—No significant differences were found for target detection accuracy, $F(1,11) = 0.238$, $p > 0.05$, and reaction time, $F(1,11) = 1.29$, $p > 0.05$.

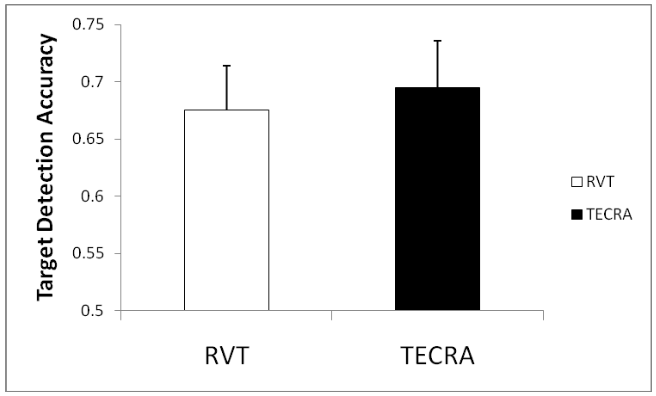


Figure 7 – Target Detection Accuracy

However, there was a trend in favor of the TECRA system. Accuracy was slightly higher in the TECRA interface condition (M = 69%, SEM = 4%) compared to the RVT condition (M = 68%, SEM = 4%) (see Figure 7). Reaction time was also slightly faster on average by 1 second in the TECRA condition (see Figure 8). Low power due to the small sample was probably the reason why this result was not significant.

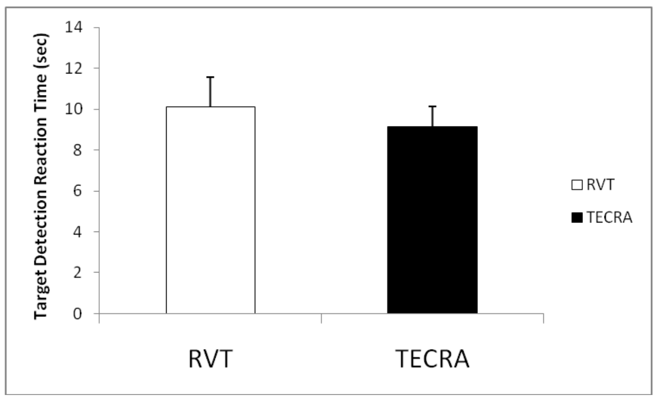


Figure 8 – Target Detection Reaction Time (seconds)

Situation Awareness—There was a significant effect for Interface Type for situation awareness accuracy, $F(1,11) = 44.57$, $p < 0.05$, and situation awareness reaction time, $F(1,11) = 15.58$, $p < 0.05$. Situation awareness accuracy was markedly higher in the TECRA condition (M = 92%, SEM = 7%) compared to the RVT condition (M = 38%, SEM = 6%) (see Figure 9). Furthermore, SA reaction time was faster in the TECRA condition (M = 5.9s, SEM = 0.9s) compared to the RVT condition (M = 9.2s, SEM = 0.9s) (see Figure 10).

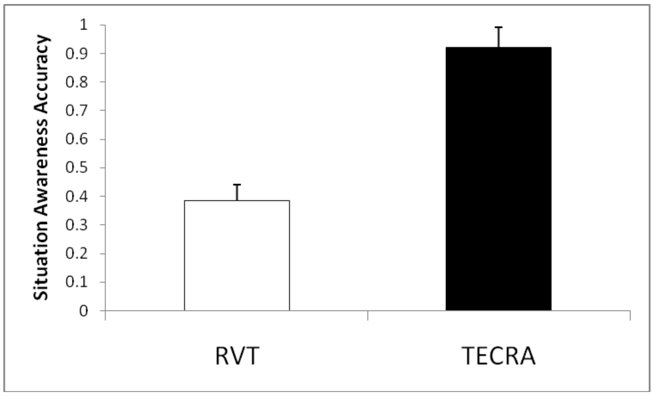


Figure 9 – Situation Awareness Accuracy

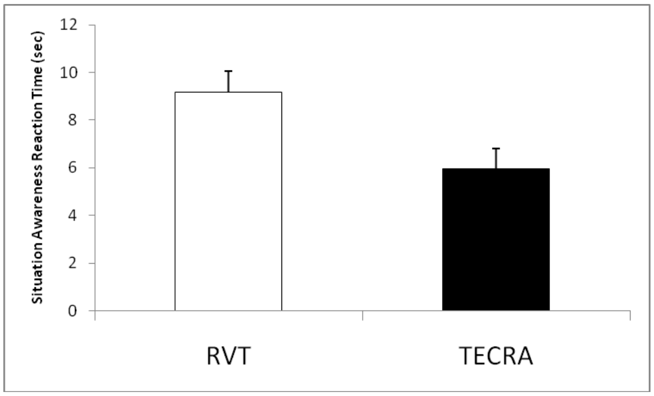


Figure 10 – Situation Awareness Reaction Time (seconds)

Subjective Workload—There was a significant effect for Interface Type for subjective workload, $F(1,11) = 6.70$, $p < 0.05$. Subjective workload was lower in the TECRA condition (M = 41.7, SEM = 3.0) compared to the RVT condition (M = 45.2, SEM = 3.4) (see Figure 11). For both systems workload was relatively low at an average of 43.5.

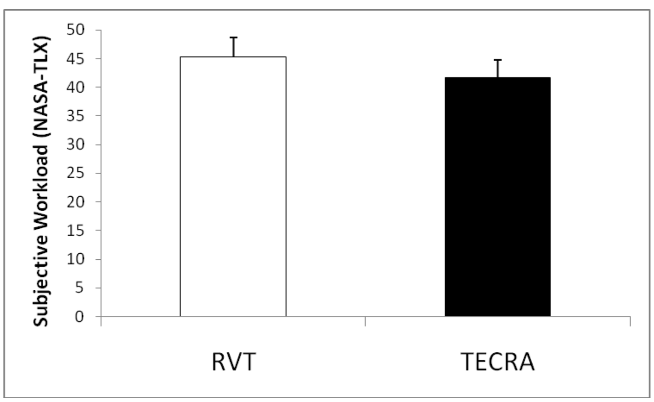


Figure 11 – Subjective Workload (NASA-TLX)

Discussion

The goal of this experiment was to compare the TECRA interface to the RVT interface in terms of performance and user experience. We found that users of the TECRA interface showed an increase in situation awareness, a reduction in situation awareness reaction time, and a reduction in subjective workload compared to the RVT system. Furthermore, trends showed that the TECRA system may improve target detection performance compared to the RVT system although these results are not reliable.

The results empirically demonstrate the efficacy of the TECRA interface. Improvements in situation awareness are vital as they can matter in time-critical situations where the timely and accurate information can save lives. In addition, reducing subjective workload was one of the major objectives of this program and cited as a critical requirement for the commander.

The results are also consistent with the original GOMS model that predicted a reduction in time needed to operate the TECRA system compared to the original RVT system. Furthermore, this experiment only consisted of a basic monitoring task. The systems were not used for making route requests, taking pictures or video clips from the live video feed, or relaying and receiving critical information from the MO. It is likely that the observed performance improvements when using TECRA for conducting a simple monitoring task would extent to benefiting a Commander when conducting additional, more complex C2 tasks. Further research will need to be conducted to measure the benefits of other TECRA functionality.

7. CONCLUSIONS

Our goal for this project was to design a system that would improve coordination and performance of SUAS crews. We did this in a systematic manner. First we analyzed the current situation by interviewing users of the Raven system and observing military exercises. We then developed our own design methodology to design an adaptive automation interface system based on previous theory [1]. We took a prototype of the interface and showed it to SMEs who provided us with feedback. Finally, we conducted an experiment to examine whether our system would improve overall performance.

The SME interviews showed that the TECRA system was easy to use, easy to learn, and added functionality that did not yet exist. The experiment showed that situation awareness improved and subjective workload was reduced when using the TECRA system in comparison to the RVT system. Taken together, these are encouraging results in favor of the TECRA system.

Several future research directions are being planned. First, we intend to further test the adaptive features of the interface in a follow-up experiment with a larger sample size. We plan to compare several conditions including a situation where there is no automation, non-adaptive (static)

automation, or user-centered adaptive automation. We also plan to conduct field tests to test the TECRA system in a real-world setting with a real Raven SUAV.

With further testing our TECRA system can improve in its design and may eventually be incorporated into existing SUAV systems.

REFERENCES

[1] Parasuraman, R., Barnes, M., & Cosenzo, K. (2007). Adaptive automation for human-robot teaming in future command and control systems. *International Journal of Command and Control*, *1(2)*, 43-68.

[2] Parasuraman, R., Cosenzo, K., & de Visser, E. (2009). Adaptive automation for human supervision of multiple uninhabited vehicles: Effects on change detection, situation awareness, and mental workload. *Military Psychology, 21*, 270-297.

[3] Cosenzo, K., Parasuraman, R., Novak, A. & Barnes, M., (2006). *Adaptive automation for robotic military systems*. ARL Technical Report, ARL-TR-3808

[4] Neumann, J., and Durlach, P.J., 2006 Effects of Interface Design and Input Control Method on Unmanned Aerial System Operator Performance. Paper No. 2882, I/ITSEC, Orlando, FL

[5] US Army, (2007a). Operator Instructions for Small Unmanned Aircraft System, SUAS, RQ-11B, NSN:1550-01-538-9256, January 9.

[6] US Army, (2007b). Technical Manual for Small Unmanned Aircraft System, SUAS, RQ-11B, NSN:1550-01-538-9256, EIC:ICB, January 9.

[7] Klein, G. A., Calderwood, R., & MacGregor, D. (1989). Critical decision method for eliciting knowledge. *IEEE Transactions on Systems, Man, & Cybernetics, 19*(2), 462-472.

ACKNOWLEDGMENT

The research and development work described here was performed as a SBIR Phase II project for the US Army Research Institute, Contract No. W91WAW-08-0079. We wish to acknowledge the invaluable help and support of our project COTR Dr. Paula Durlach, as well as that of the Army personnel and contractors associated with the Raven SUAV system. We also wish to thank Jonathan Lamon for building the TECRA software system.

BIOGRAPHIES

Ewart de Visser *is pursuing a Ph.D. degree in Human Factors and Applied Cognition at George Mason University. He is also currently employed as a Junior Human Factors Scientist at Perceptronics Solutions, Inc. Ewart's current research is mainly within the unmanned systems domain and focuses on human automation interaction, trust, adaptive automation, human-automation etiquette and decision support systems. He also specializes in developing, evaluating, and enhancing adaptive interfaces to support unmanned vehicle systems. Ewart received his B.A. in Film Studies from the University of North Carolina at Wilmington and a M.A. in Human Factors and Applied Cognition from George Mason University.*

Dr. Melanie LeGoullon *is a Human Factors researcher at Perceptronics Solutions' Washington, D.C. office. She has extensive experience conducting human factors and cognitive research within the aviation industry. Melanie's expertise is centered on human error in automated systems; she has collaborated with several airlines to improve pilot performance in highly automated cockpits, and is herself a private pilot. Dr. LeGoullon holds a B.A. in Biology from Cornell University and a M.A. and Ph.D. in Cognitive Psychology from George Mason University. While pursuing her Ph.D., Melanie was also a fellow in NASA's prestigious Graduate Student Researchers Program.*

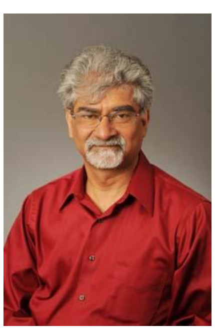
Don Horvath *is a Human Factors Scientist at Perceptronics Solutions, Inc., where he specializes in the design and evaluation of collaborative systems. Don received his Master's Degree in Human Factors and Applied Cognition from George Mason University and his Bachelor's Degree in Psychology from the University of Pittsburgh at Johnstown.*

Dr. Gershon Weltman *is Principal Scientist and Vice President of Perceptronics Solutions, Inc. and also serves as Lecturer at UCLA's School of Engineering and Applied Science, where he teaches the required ethics course "Engineering and Society." Prior to forming Perceptronics Solutions, he was CEO and Chairman, of Perceptronics, Inc., a high technology R&D and manufacturing company.*

Dr. Weltman's professional experience is centered on the area of human and team performance and on the design, development and delivery of innovative and complex computer-based simulation and decision support systems. Dr. Weltman was a six-year member of the U.S. Army Science Board, where he participated in studies focusing on training and simulation, and chaired studies on human behavior in combat and on US small arms production. Dr. Weltman has published numerous scientific, technical and strategic papers, and has presented many lectures and briefings at government, business and professional meetings.

***Dr. Amos Freedy** is a recognized expert in planning and managing large scale development and production programs involving a combination of engineering and behavioral disciplines, with special emphasis on AI and cognitively aided human-computer systems. Amos previously was president and chief operating officer of Perceptronics, Inc., a public corporation which he co-founded with Gershon Weltman. At Perceptronics, Inc., Amos served as a principal investigator on numerous AI-based decision modeling and aiding programs for defense agencies and commercial firms. His main role was management of projects through proof of concept and field implementation including software development and hardware system design and integration. In particular, Amos directed a multi-year program for DARPA and ONR establishing the pioneering principles and practice of computer-based group decision aiding. Amos has served as Chairman of the Man-Machine Committee and of the Decision Subcommittee for the IEEE Systems, Man and Cybernetics professional society and has published numerous technical and strategic articles, papers, reports and book chapters. He received a BS in Electrical Engineering, a MS in Bio-Engineering and a PhD in Electronics and Man-Machine Systems from the UCLA School of Engineering and Applied Science.*

***Dr. Paula Durlach** has conducted training research at the Orlando unit of the U.S. Army Research Institute for the Behavioral and Social Sciences for the past 8 years. She currently leads a project on adaptive training technology, the goal of which is advance the ability of technology-based training to diagnose performance and adapt training content to cure deficiencies. Dr. Durlach holds a Ph.D. in Experimental Psychology from Yale University.*



***Dr. Raja Parasuraman** has been Professor of Psychology at George Mason University, Fairfax, VA since 2004. In 2007 he was appointed to the position of University Professor at George Mason University. He is Director of the Graduate Program in Human Factors and Applied Cognition. He is also Chair of the Neuroimaging Core of the Krasnow Institute (NICKI). Previously he held appointments as Professor and Associate Professor of Psychology at The Catholic University of America, Washington DC from 1982 to 2004. He received a B.Sc. (1st Class Honors) in Electrical Engineering from Imperial College, University of London, U.K. (1972) and an M.Sc. in Applied Psychology (1973) and a Ph.D. in Psychology from the University of Aston, Birmingham, U.K. (1976).*